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April 12, 1966 K. D. KRYTER 3,246,084

METHOD OF AND APPARATUS FOR SPEECH COMPRESSION AND THE LIKE

Filed Aug. 26, 1960 4 Sheets-Sheet 1

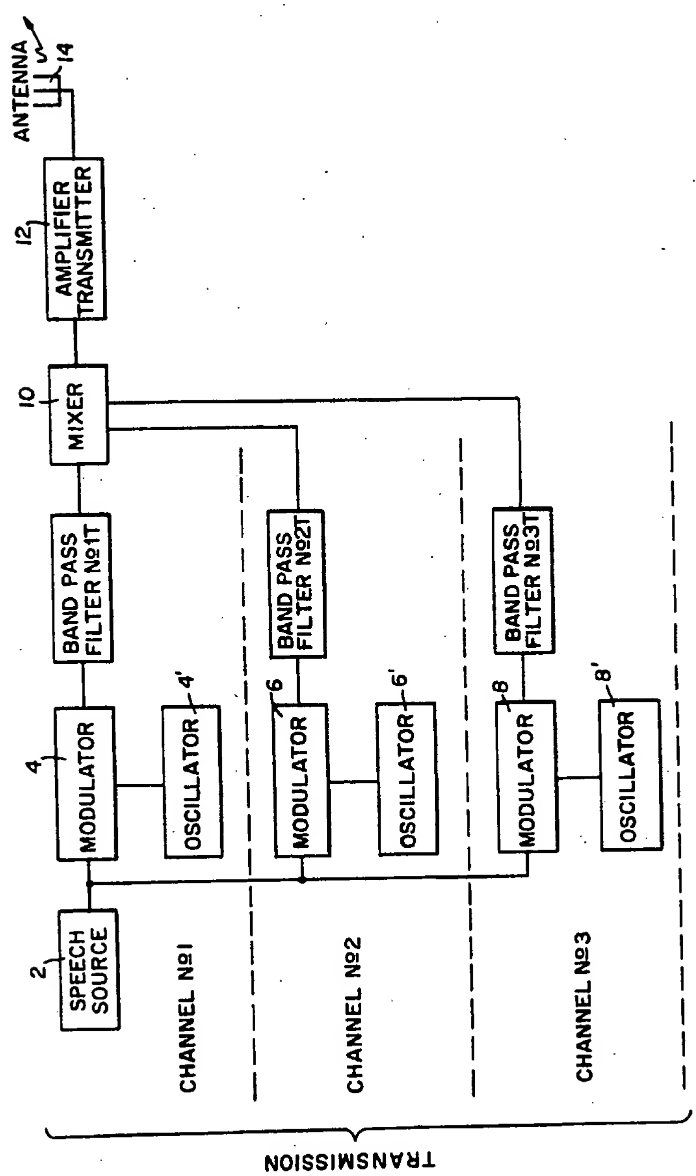


FIG. IA

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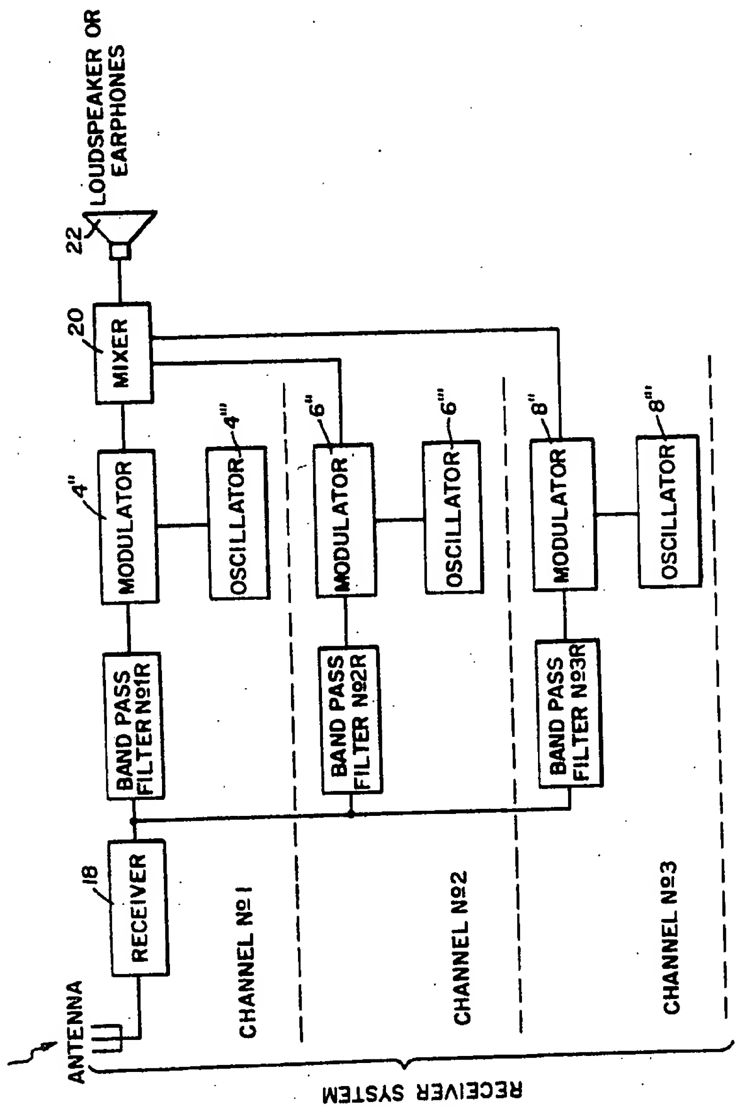


FIG. 1B

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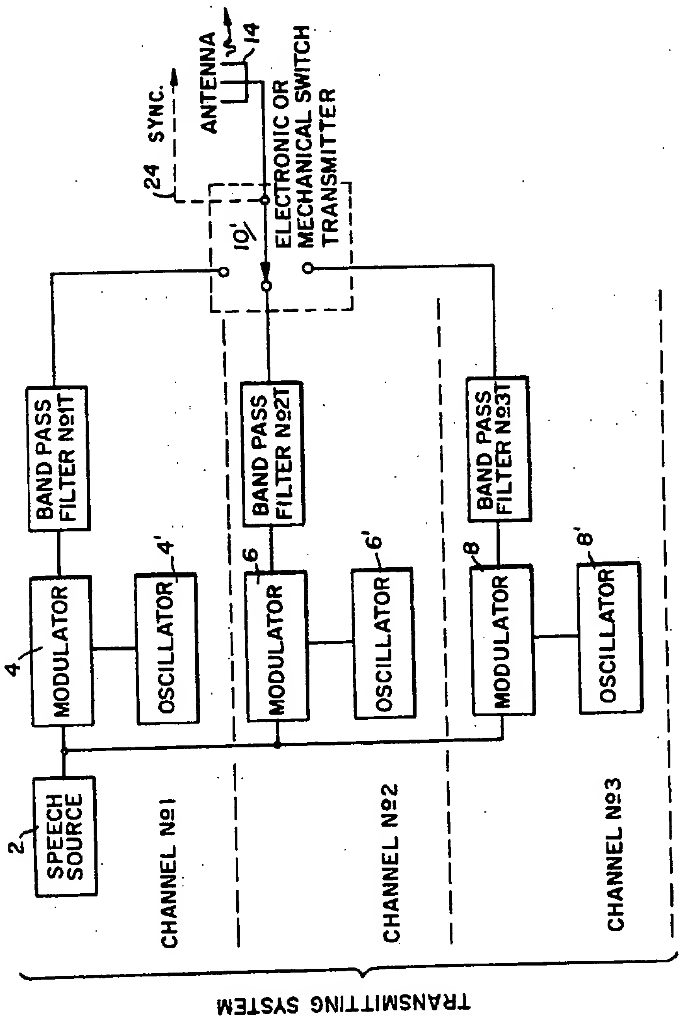


FIG. 2A

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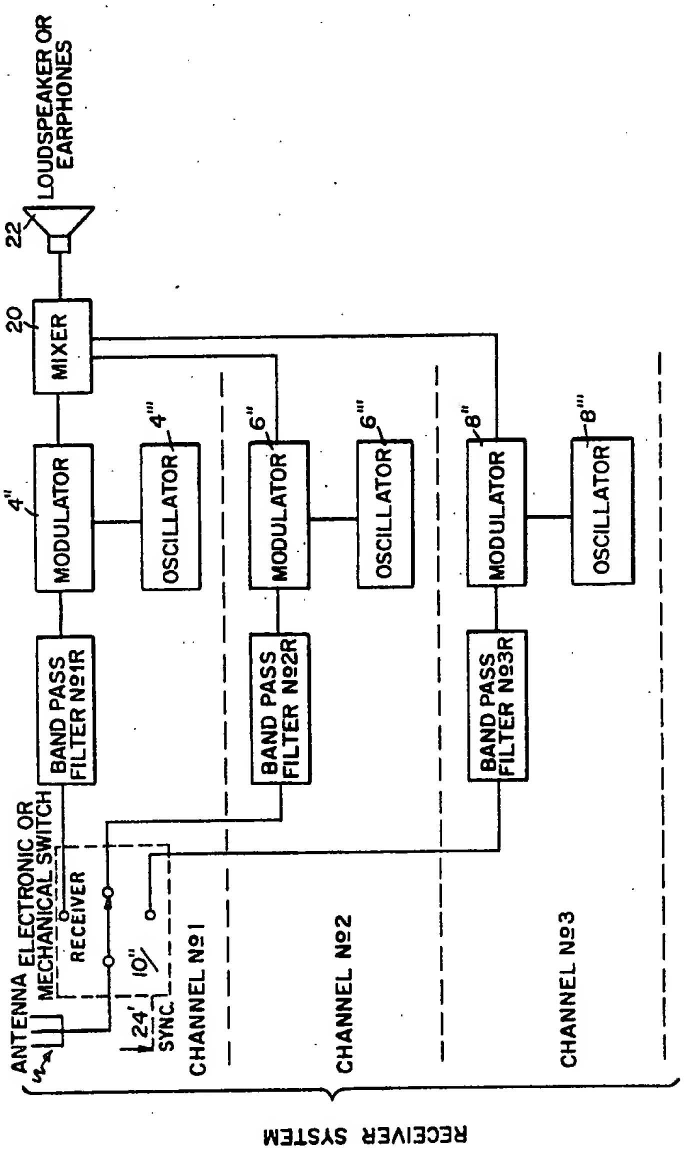


FIG. 2B

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METHOD OF AND APPARATUS FOR SPEECH COMPRESSION AND THE LIKE

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4 Claims. (Cl. 179—15.55)

The present invention relates to methods of and apparatus for compressing the bandwidth of signals to be transmitted, and restoring the transmitted signals, upon reception, to the original uncompressed state thereof; the invention being more particularly concerned with the problems of speech compression and the like.

The art is replete with proposals for producing speech compression and the like, this having been a problem that has existed since the early days of commercial telephony and which has been vigorously attacked by those skilled in the art for at least the past three to four decades. Among numerous proposals for solving the problem of reducing the necessary bandwidth for the transmission of speech signals and the like, without unsatisfactorily distorting the signals, are various types of signal sampling circuits based both upon time and frequency spectrum sampling. In some systems, spectrum sampling alone is used; in others, time sampling is employed; in still others, a combination of time and spectrum sampling has been proposed. In still other proposals, narrow bands of frequencies are selected from the speech signal and distortion devices are employed at the reproducing end to provide energy for filling in the gaps between the selected narrow bands of frequencies. All such prior-art proposals, however, have been subject to the difficulty that the bandwidth saving consistent with intelligibility, has been most restrictive.

An object of the present invention is to provide a new and improved method of and apparatus for signal compression that is not subject to the above-mentioned disadvantages of the prior art, but that, to the contrary, represents a marked advance in the available degree of speech compression and the like, consistent with excellent intelligibility.

A further object is provide new and improved signal compression transmitting and reproducing apparatus for such purposes as speech compression and the like, and for more general use, as well.

An additional object is to provide a new and improved signal compression transmitter.

Still a further object is to provide a novel signal compression receiving and reproducing apparatus.

Other and further objects will be explained hereinafter and will be more particularly pointed out in connection with the appended claims.

In summary, the invention involves a method of and apparatus for transmitting and reproducing a signal, such as speech, having components extending over a predetermined relatively low-frequency band. A signal source is connected to a first plurality of channel circuits each corresponding to a different predetermined frequency sub-band only, within the said predetermined relatively low-frequency band, each sub-band being frequency-separated from the other sub-bands. The channel circuits are each provided with means for producing, in the preferred embodiment of the invention, a plurality of further frequency-contiguous relatively high-frequency bands of overall bandwidth less than that of the said predetermined relatively low-frequency band. Each of the contiguous high-frequency bands corresponds to one of the separated sub-bands and means is provided for transmitting the contiguous frequency bands along a common channel

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and for receiving the same. A second plurality of channel circuits is connected with the receiving means, one corresponding to each of the first plurality of channel circuits and each provided with means for converting the received contiguous frequency bands back into the said frequency-separated sub-bands, representing the sampled original signal. Preferred constructional details and modifications are later set forth.

The invention will now be described in connection with the accompanying drawing, FIGS. 1A and 1B of which are block diagram views of the transmitting and receiving apparatus portions of a preferred embodiment of the transmitting and reproducing invention herein described and claimed; and

FIGS. 2A and 2B are similarly views of a modification.

Assume, for example, that three frequency sub-bands, separated from one another in the speech-signal frequency band, are extracted therefrom. If the sub-bands are then, in effect, juxtaposed, the combined total bandwidth thereof will be much less than that of the total speech-signal band, and may thus be transmitted with such lesser or compressed bandwidth. In reception, the three transmitted juxtaposed sub-bands may be separated out and restored to their normal frequency-separated positions in the speech frequency band, reproducing the speech frequency signal as a three sub-band-sampled signal. Alternatively, the extracted sub-bands at the transmitter may be appropriately sequentially transmitted, again with much compressed bandwidth; this time equal to that of the individual sub-bands.

Under appropriate conditions, it has been found that speech passed through several half-octave band pass filters, corresponding to the above-mentioned sub-bands, separated or spaced at appropriate intervals along the speech spectrum or band, is more intelligible than is predicted on the basis of the Articulation Index. In fact, if constant speech intelligibility is used as the criterion, the present invention produces results that indicate that the total effective bandwidth required for the multiple pass band system is less than that required for the best contiguous pass band systems by a factor of two or three. A further feature of the invention resides in the discovery that the signal resulting from this particular type of multiple sampling in the frequency domain sounds natural and the identity of a talker's voice appears to be maintained.

Referring to the transmission system of FIG. 1A, a source **2** of speech-frequency signal, extending, as an illustration, over a predetermined band of frequencies up to five thousand cycles per second, more or less, is connected to each of the modulators **4**, **6** and **8** of each of three channels, labelled No. **1**, No. **2**, and No. **3**, to speech-modulate the frequencies generated in corresponding channel oscillators **4′**, **6′** and **8′**. The modulators **4**, **6** and **8** feed a common channel mixer **10** through respective speech sub-band band pass filters, No. **1T**, No. **2T** and No. **3T**. The combined signal in the mixer **10** may be amplified at **12** and transmitted as, for example, free-space radio signals from an antenna **14**.

In accordance with a preferred embodiment of the present invention, the sub-bands filtered by the band pass filters are of substantially identical bandwidth B, with the center frequencies thereof separated or spaced by a frequency band ΔF. For a three sub-band system, for example, B could by 500 cycles and ΔF could be 1000 cycles, with the separated speech sub-bands, corresponding to the three channels No. **1**, No. **2** and No. **3**, being 100–600 cycles, 1100–1600 cycles and 2100–2600 cycles, respectively. By proper selection of the carrier frequencies above the speech-frequency range, in the three channel oscillators **4′**, **6′** and **8′**, and by proper selection of

the bandwidth and center frequencies of filters No. 1T, No. 2T, and No. 3T, the separated selected sub-bands, now being modulated, are made contiguous with one another. For radio carrier frequencies of, for example, 10,000 cycles for the oscillator 4', 9,500 cycles for the oscillator 6' and 9,000 cycles for the oscillator 8', and filter No. 1T set for a bandwidth of 500 cycles and a center frequency of 10,350 cycles, filter No. 2T set for a bandwidth of 500 cycles and a center frequency of 10,850 cycles, and filter No. 3T set for a bandwidth of 500 cycles and a center frequency of 11,350 cycles, the band pass filters will pass the following bands: filter No. 1T, 10,100–10,600 cycles; filter No. 2T, 10,600–11,100 cycles; and filter No. 3T, 11,100–11,600 cycles from the upper side band of the modulated signal. The envelope of the signal at the output of filter No. 1T corresponds to the original speech frequencies in the frequency region from 100–600 cycles, the envelope of the signal at the output of filter No. 2T corresponds to the original speech frequencies in the frequency region from 1100–1600 cycles, and the envelope of the signal at the output of filter No. 3T corresponds to the original speech frequencies in the frequency region from 2100–2600 cycles. It will thus be observed that the spech modulated frequency bands emerging from the bandpass filters No. 1, No. 2 and No. 3 have thus been rendered frequency-contiguous even though they represent sub-bands of speech that are separated from one another; and that the bandwidth of the combined output of the mixer 10 extends from 10,100 to 11,600 cycles, representing a bandwidth equal only to the sum of the original three 500-cycle speech sub-bands (1500 cycles), which is only a fraction of the original 5000 cycle speech-signal bandwidth. An appreciable factor of bandwidth compression has thus been achieved.

The transmitted compressed-bandwidth signal may be received at 18, FIG. 1B and fed through corresponding three-channel bandpass filters No. 1R, 2R and 3R, the outputs of which beat or heterodyne, in respective modulators 4'', 6'' and 8'', with appropriate local oscillator frequencies from the respective channel oscillators 4''', 6''' and 8'''. In accordance with the present invention, the bandpass frequencies of the filters No. 1R, 2R and 3R, and the frequencies of the oscillators 4''', 6''' and 8''' are critically selected to separate out the transmitted contiguous three speech sub-bands into the original three separated speech sub-bands, thereby to reproduce the original sub-band-sampled speech signal. If for example, the bandpass filters No. 1R, 2R and 3R are respectively adjusted to correspond in frequency-adjusted bandpass to that of the corresponding transmitter bandpass filters No. 1T, 2T and 3T (namely, 10,100–10,600 cycles; 10,600–11,100 cycles; and 11,100–11,600 cycles, respectively), and oscillators 4''', 6''' and 8''' are respectively tuned to frequencies of 10,000 cycles, 9,500 cycles and 9,000 cycles, beat-difference frequencies corresponding to the original separated speech sub-bands 100–600 cycles, 1100–1600 cycles, and 2100–2600 cycles will be separated out. The mixer 20 will then reproduce in loudspeaker 22 the original sub-band-sampled speech signal. As before stated, this has been found, in accordance with the present invention to produce an intelligibility greater than one would predict on the basis of the Articulation Index.

The number of channels correspondings to the number of speech sub-frequency bands selected and transmitted and received may, of course, be more or less than the illustrative example of three. The carrier frequencies involved, moreover, may be in a vastly different frequency range than in the above example. As a further illustration, six speech sub-bands may each be of width $B=100$ cycles, and the channel oscillator frequencies may be of the order of 200 kc. The first channel oscillator 4' may have a frequency of 200 kc., more generally designated by the symbol $F_1$. If the space between the uppermost



frequency of the first channel band and the lowermost frequency of the second channel band is represented by $\Delta F$, then the second channel oscilator frequency $F_2$ will be determined by the expression $F_2=F_1+\Delta F$; and so on, for the remaining channels. In all cases, the same juxtaposing of the originally separated sub-bands, and the same later respacing of the sub-bands in accordance with their original separation will be produced, as above described.

The compression effected by combining the originally separated speech sub-bands (in their modulation form) in the system of FIG. 1A, is not the only possible manner of compression. In the system of FIG. 2A, for example, the oscillators 4', 6' and 8' are tuned so that the output of each of the band pass filters No. 1T, 2T and 3T, will have the same center frequency, but will represent the information in the different originally separated speech sub-bands B. For the previous example of the three separated sub-bands 100–600 cycles, 1100–1600 cycles, 2100–2600 cycles, corresponding to each of channels No. 1, No. 2 and No. 3, oscillator 4' may be tuned to 12,000 cycles; oscillator 6', to 11,000 cycles; and oscillator 8', to 10,000 cycles. Each of the 500-cycle band pass filters No. 1T, 2T, 3T will be tuned to the same center frequency of 12,350 cycles, though the output thereof represents the different intelligence in each of the respective 100–600 cycle, 1100–1600 cycle and 2100–2600 cycle speech sub-bands. A common channel frequency transmitter 10' may thus be employed to transmit a common frequency, of the same single contiguous sub-band 500-cycle bandwidth, on a sufficiently rapid sequential time-shared basis, schematically illustrated by the switch 10' labelled "Electronic or Mechanical Switch Transmitter" and successively and repetitively engaging the outputs of filters No. 1T, 2T and 3T. Any of the well-known time-sharing or sequential transmitters may, in practice, be employed, so that the details thereof are not herein illustrated since they form no part of the novelty of the present invention and would only serve to complicate the drawings and detract from the essential novel features of the present invention.

The successively transmitted signals, the bandwidth of which has been compressed from, for example, a 5,000 cycle total speech-signal bandwidth, to one-tenth that bandwidth or 500 cycles, may be received in well-known conventional time-sharing or sequential receiving apparatus, schematically illustrated by the switching mechanism 10'', FIG. 2B, labelled "Electronic or Mechanical Switch Receiver." The receiver 10'' distributes the successively switched transmitted signals to respective channel band pass filters No. 1R, 2R and 3R (corresponding to the transmitter filters No. 1T, 2T and 3T), in synchronism with the sequential operation of the transmitting switching 10', FIG. 2A, as under the control of well-known synchronizing signals SYNC, transmitted and received at 24 and 24', respectively. Through appropriate tuning of the receiver oscillators 4''', 6''' and 8''', the original 100–600 cycle, 1100–1600 cycle, and 2100–2600 cycle sub-bands will, as before explained, be separated out and fed through mixer 20 for reproduction as the original sub-band-sampled speech signal, in the loudspeaker 22.

Again, as in the case of the embodiment of FIGS. 1A and B, more or less than three channels may, if desired, be employed. While the invention is of particular importance in connection with speech signals, it may also be employed in other frequency ranges, also, where the advantages of the invention are desired.

Further modifications will occur to those skilled in the art and all such are considered to fall within the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. Apparatus for transmitting and reproducing a signal having components extending over a predetermined fre-

quency band, the apparatus having, in combination, a signal source, a first plurality of channel circuits connected to the source and each corresponding to a different predetermined frequency sub-band only within the said predetermined frequency band, each sub-band being frequency separated from the other sub-bands by a predetermined, fixed, substantial frequency gap so as to sample the signal, the channel circuits being each provided with conversion means for producing contiguous further frequency bands of overall bandwidth less than that of the said predetermined frequency band and of higher frequency than the sub-bands and corresponding to the separated sub-bands but without any frequency gaps therebetween, the conversion means of each of said circuits comprising oscillator means generating an effectively constant carrier frequency different from the carrier frequency of the other oscillator means, modulator means having an input applied from the associated oscillator means and said source for producing an output in one of said further frequency bands, and band-pass filter means receiving the output of the associated modulator means and for passing one of said further frequency bands, means for transmitting the further bands along a common path, and means for receiving the same comprising a second plurality of channel circuits, one corresponding to each of the first plurality of channel circuits and provided with means for converting the received further bands back into the said frequency-separated sub-bands, thereby to reproduce the said sampled signal.



2. Apparatus as claimed in claim 1 and in which the said signal source comprises a source of speech-frequency signals, and the said oscillators and band-pass filters are tuned to radio frequencies.

3. Apparatus as claimed in claim 1 and in which the means for converting the received further bands back into the said frequency-separated sub-bands comprises, for each of the said second plurality of channel circuits, a further band-pass filter, modulator and oscillator.

4. Apparatus as claimed in claim 1 and in which said transmitting and receiving means comprise synchronously operated means for transmitting and receiving the further bands in time sequence.

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